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Ontwerp van een (warmtepomp)installatie met betonkernactivering

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Warmtepomp Symposium
Sint-Katelijne-Waver, 11 september 2013

Content

- Why TABS?
- Three thermal characteristics
- Learning from a case-study
- Controller design
- Conclusions

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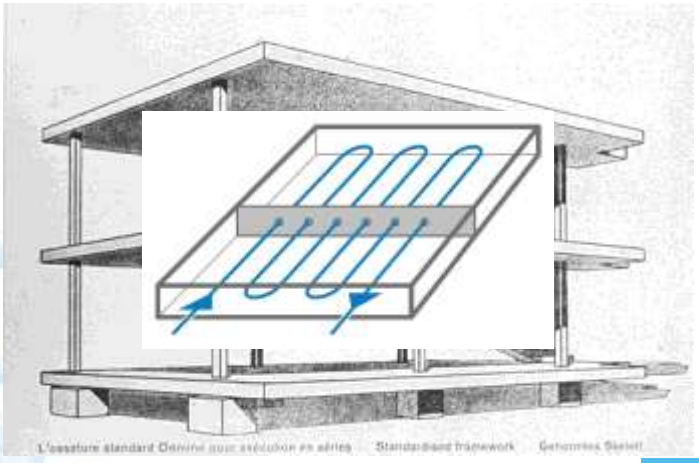
Thermally Activated Building Systems (TABS) or Concrete Core Activation (CCA)



Le Corbusier, L'ossature standard Domino

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Why TABS?

- Radiative heating/cooling more comfortable
- Low temperature heating/high temperature cooling
  - Heat pumps, ground cooling, night cooling
- Large thermal mass
  - Heat/cold storage
  - TABS uncouples heat/cold production from heat/cold emission

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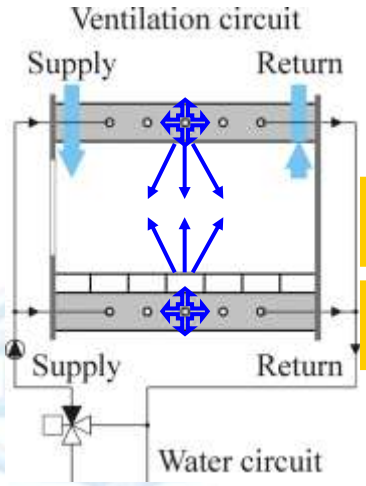
Controlled input / uncontrolled output



~ $(T_{ceiling} - T_{zone})$

~ $(T_{floor} - T_{zone})$

Heat transfer CCA-zone

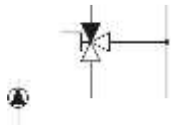
Not controllable

Heat transfer water-CCA

Controllable

Temperature control

Flow rate control



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Three thermal characteristics

- Limited steady state thermal power
- Large thermal mass → large time constant
- Large thermal power from water to TABS (in transient regime)

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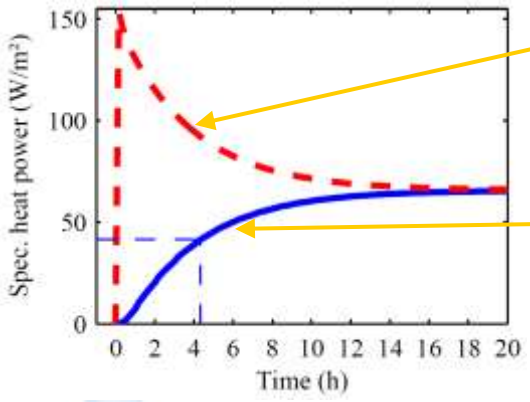
Three thermal characteristics

- Uncovered 20 cm concrete slab
- Step change in water supply from 20°C to 30°C



Thermal power input: water → TABS

Thermal power output: TABS → zone below+above

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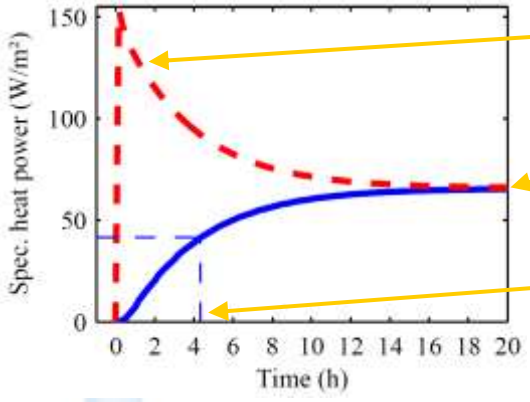
Three thermal characteristics

- Uncovered 20 cm concrete slab
- Step change in water supply from 20°C to 30°C



Large transient thermal power input

Limited steady-state thermal power

Large thermal time constant

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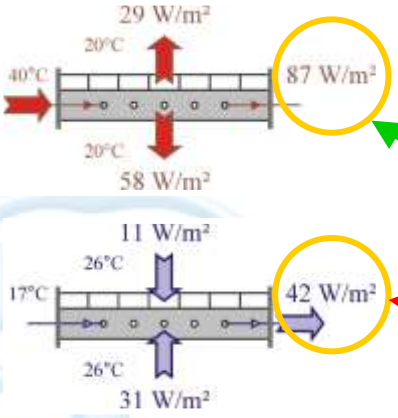
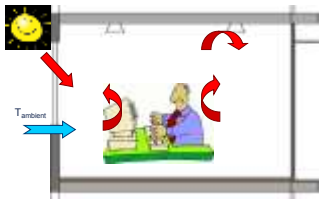
Limited thermal power - building thermal loads

- TABS with raised floor and heat pump / direct cooling





- Heat loss
  20 to 40 W/m²
- Heat load
  20 to >100 W/m²

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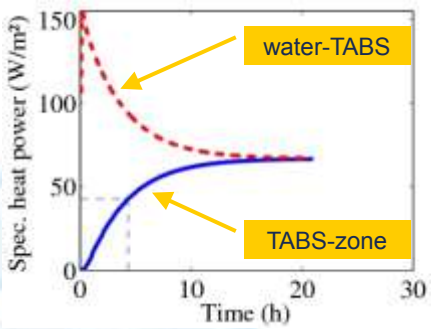
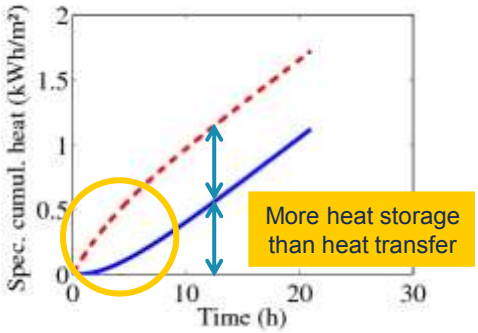
Large thermal mass

- Step change in water supply from 20°C to 30°C
- Thermal power



- Thermal energy



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Large thermal mass: example 1

- 1 cm of reinforced concrete = 6 Wh/m²K
  - e.g. increasing a 20 cm concrete slab with 1 K: 120 Wh/m²
  - e.g. a K30 building, U_{mean} = 0.36 W/m²K, 75 m² floor area, 2 levels, 0°C outdoor, 20°C indoor: 670 Wh/m² heat loss in 24 h
  - e.g. with 30 W/m² available: ~ 4 h run time for 1 K-increase of 20 cm concrete slab

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Large thermal mass: example 2

- Nathan, Duiven (The Netherlands)

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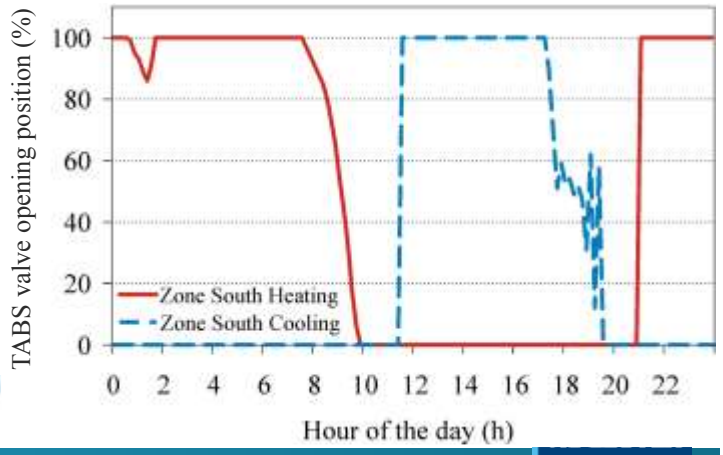
Large thermal mass: example 2

- Well designed system, but **unadapted control strategy**

Heating:
T_z < 21°C

Cooling:
T_z > 22.5°C



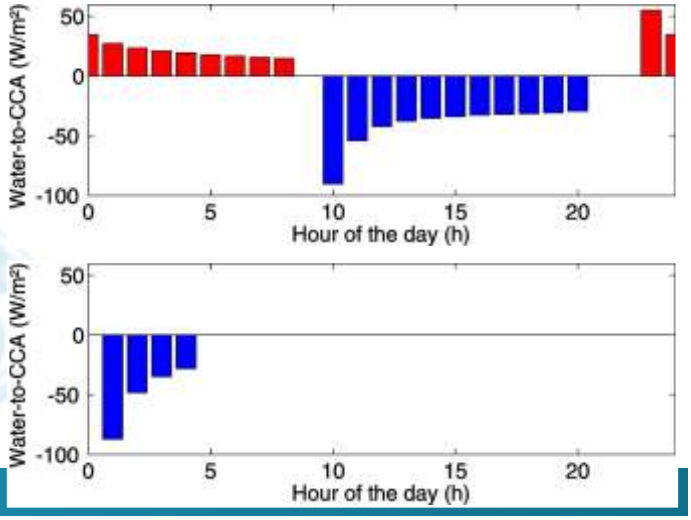
Large thermal mass: example 2

- Compared to 'Only Cooling control strategy'

Heating:
T_z < 21°C

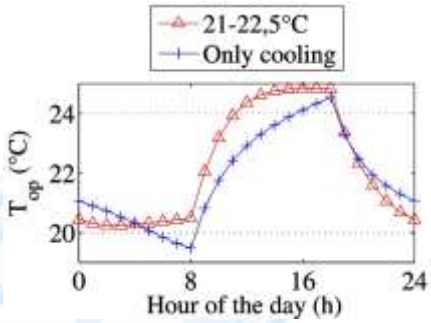
Cooling:
T_z > 22.5°C

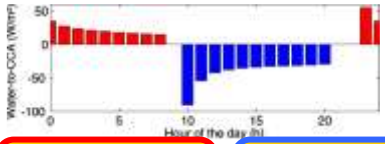
Cooling:
0h – 4h



Large thermal mass: example 2

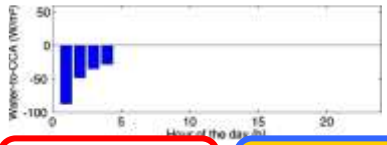
- Compared to 'Only Cooling control strategy'





Heating: 430 Wh

Cooling: 270 Wh



Heating: 0 Wh

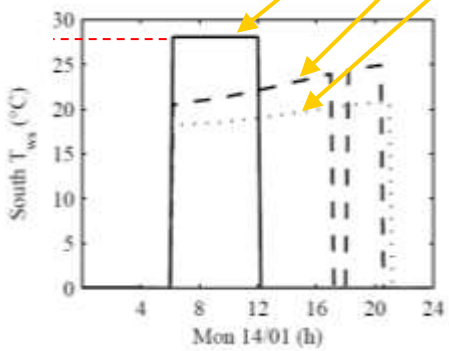
Cooling: 170 Wh

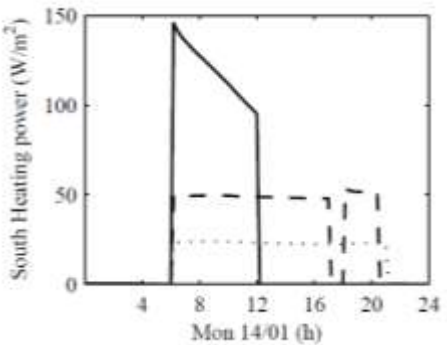
Large thermal power from water to TABS

Unlimited

50 W/m²

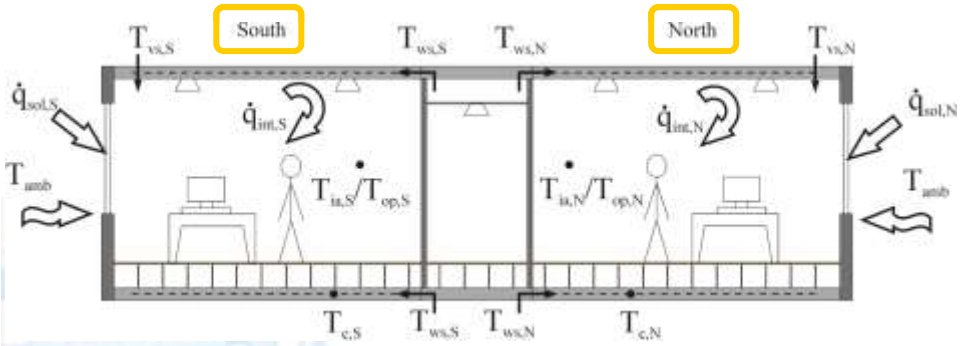
25 W/m²





TABS + building: controller design

- Building that fits TABS



- Heating load: **26 W/m²**
- Cooling load: **25 W/m²** (office hours average)

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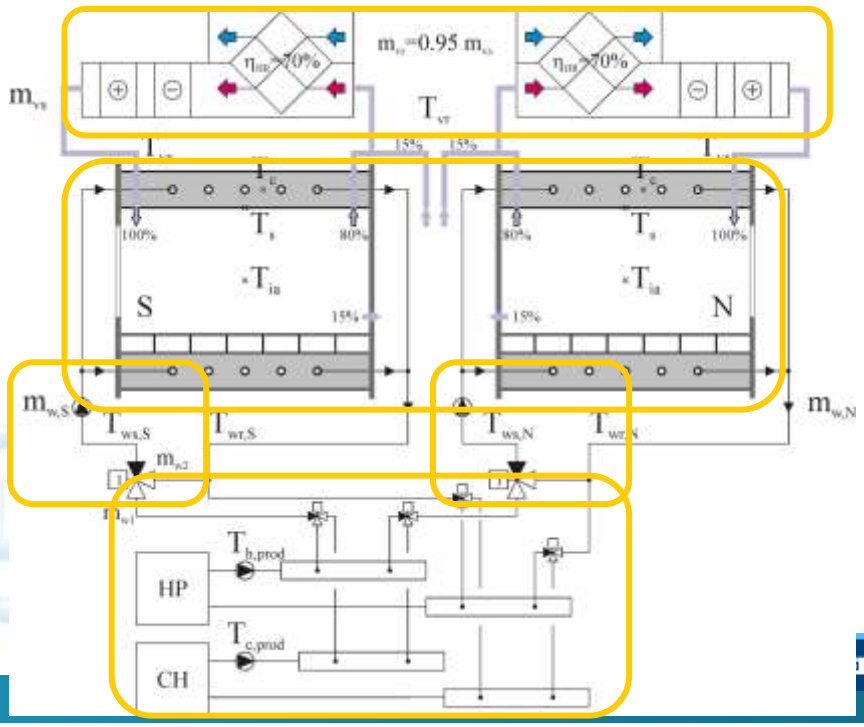


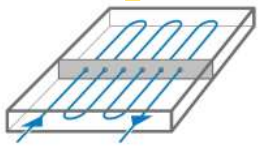
Goal

Fast

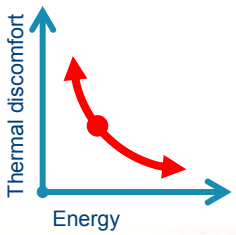
High exergy heat/cold production

CONTROL

Low exergy heat/cold production from sustainable energy sources



Slow



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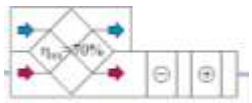
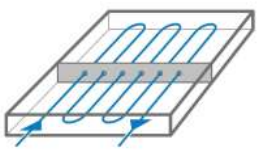
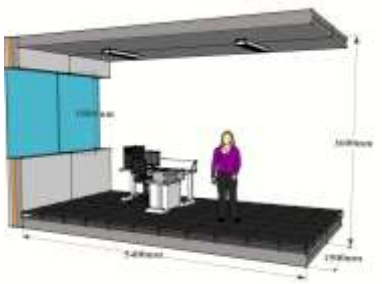
Methodology







‘Conventional’ rule-based control (feedback, if-then)

Model based Predictive Control (MPC)

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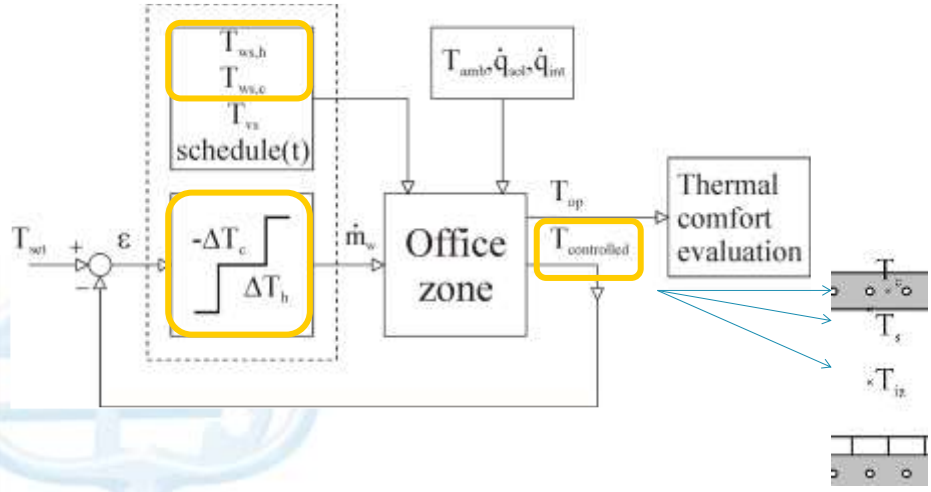
TABS + building: Rule based control



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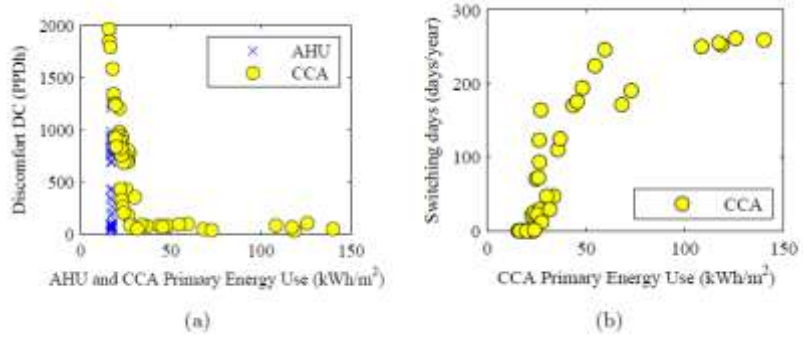
TABS + building: Rule based control



No heating and cooling of TABS during 1 day

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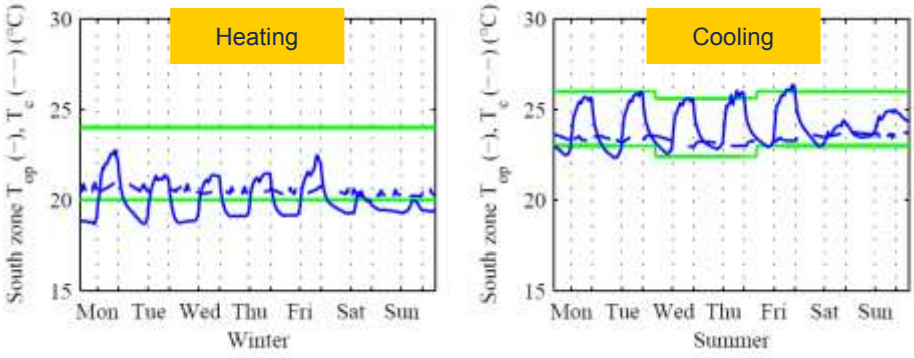
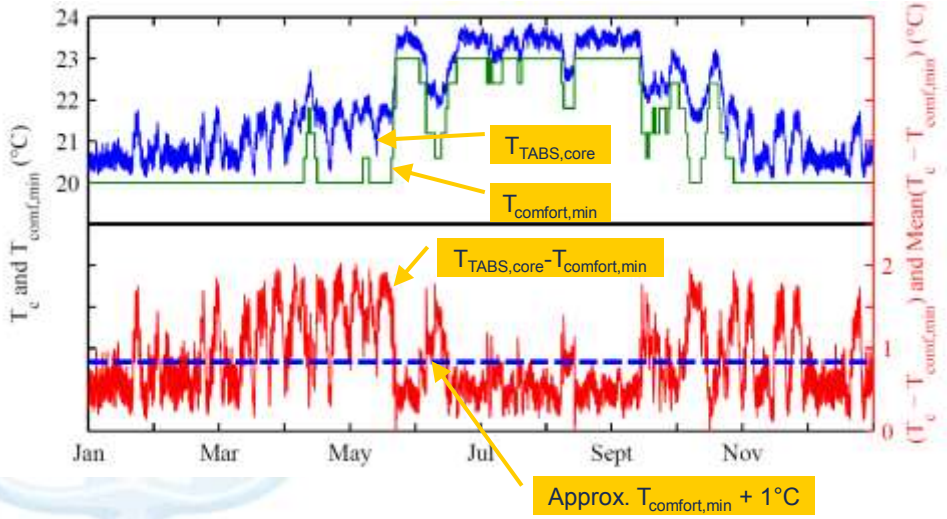
TABS + building: Rule based control

- Best results: keep TABS at temperature
  - $T_{controlled}$ = $T_{ceiling}$
  - Heating on: $T_{comfort,min}$
  - Cooling on: $T_{comfort,max}$ – 2°C
  - Heating/cooling curve: +3°C/-3°C
  - No night setback

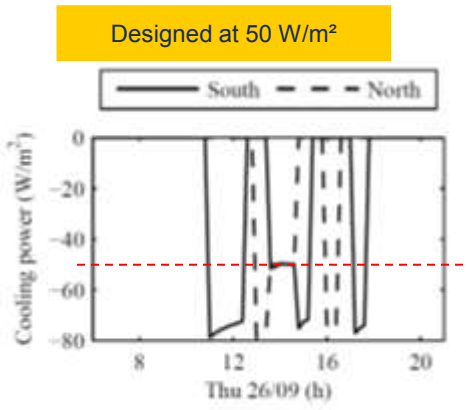


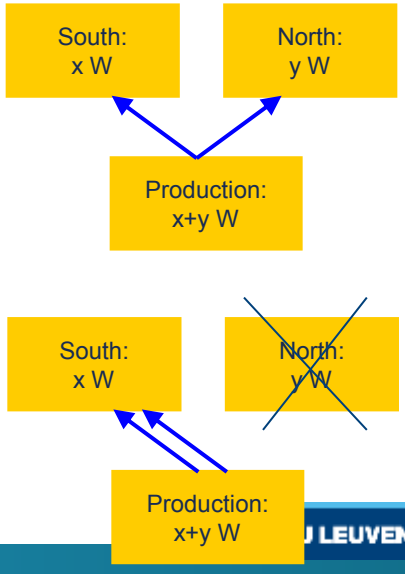
Rule based feedback control



TABS + building: Rule based control

- Alternating zone operation

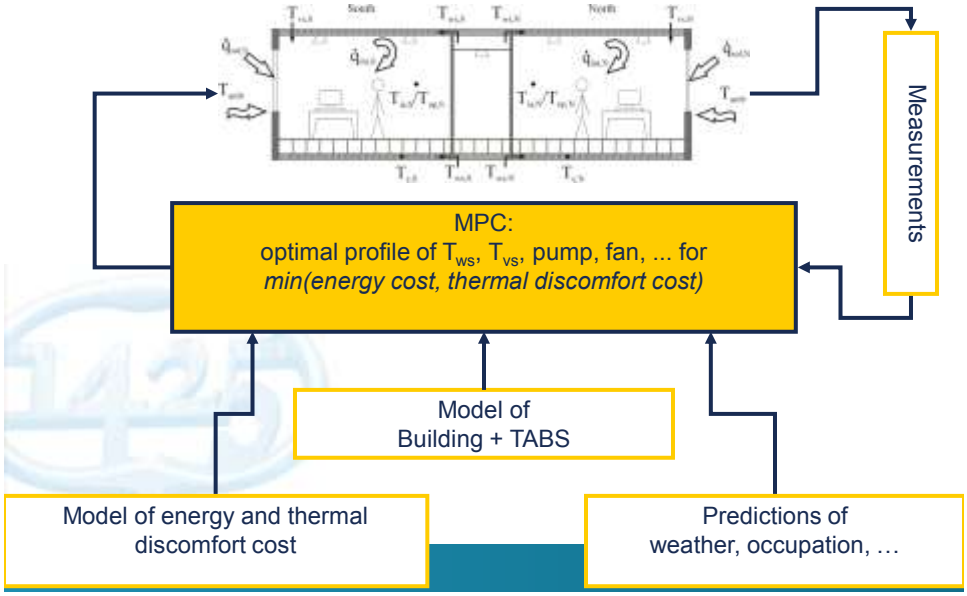




TABS + building: MPC

- Optimal use of thermal inertia
- Combination of TABS and fast reacting system:
  - Air Handling Unit
- Possible solution with
  MPC (Model based Predictive Control)

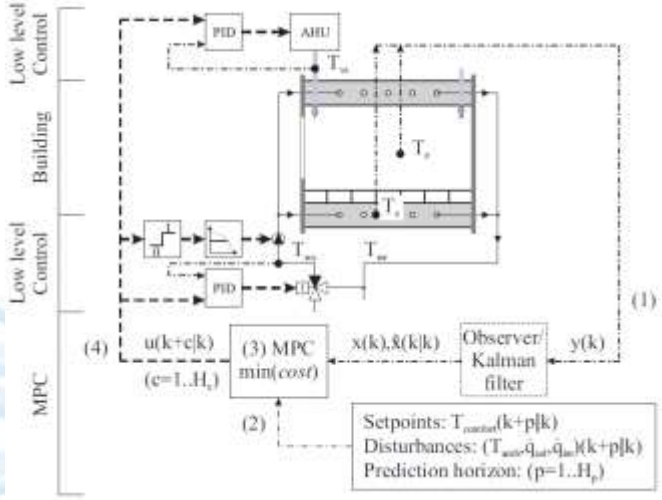
TABS + building: MPC



MPC description

TRNSYS + MATLAB

MATLAB + ACADO (OCP)



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MPC description: optimal control problem

H_c = 24h
H_p = 48h

TABS $E_{prim.}$ Heating+Cooling

AHU $E_{prim.}$ Heating+Cooling

$$\min_{T_{ws},T_{vs}} \sum_{k=0}^{H_p} \left(\left[J_{ew,h}(k) + J_{ew,c}(k) + J_{ev,h}(k) + J_{ev,c}(k) \right] F_1 \ldots \right.$$

$$\left. \ldots + \left[\alpha_{du} J_{du}(k) + \alpha_{do} J_{do}(k) \right] (1 - F_1) F_2 \right) \Delta t_c$$

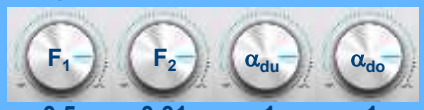
1h

Thermal discomfort Under+Over

Constraints:

- 2nd order building model
- Initial temperatures ('measured')
- Limited T_{ws} and T_{vs}
- Limited thermal production power

Tuning:



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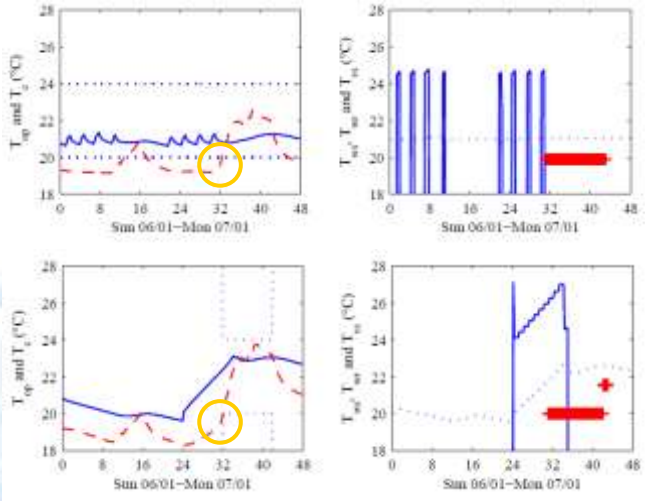
Results: heating control comparison

Rule Based (C^4)

Model Based (MPC)



Legend:
Left fig.
- T_{op}
- T_c (core)
- $T_{comfort\text{-}band}$

Right fig.
- T_{ws} (water)
- T_{wr} (water)
- T_{vs} (vent.)

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Results: heating control comparison

Rule Based (C^4)

Model Based (MPC)

Controller	$E_{TABS,prim}$ (kWh/m^2)	$E_{AHU,prim}$ (kWh/m^2)	$E_{TOT,prim}$ (kWh/m^2)	DC (Kh)
C^4	0.20	0.06	0.25	0.02
MPC	0.38	0.06	0.43	0.00

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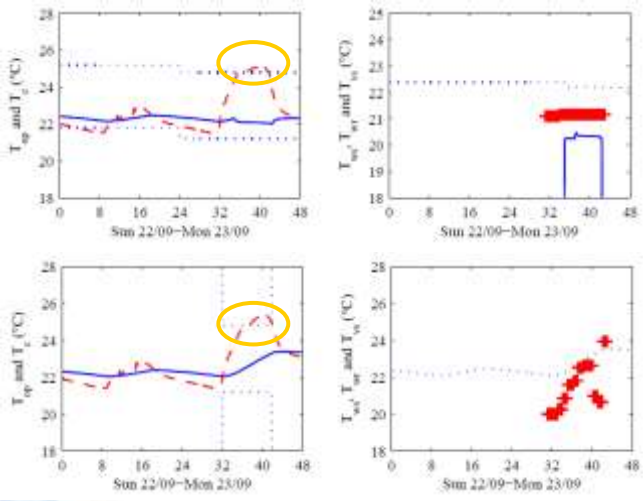
Results: cooling control comparison

Rule Based (C^4)

Model Based (MPC)



Legend:
Left fig.
- T_{op}
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Right fig.
- T_{ws} (water)
- T_{wr} (water)
- T_{vs} (vent.)

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Results: cooling control comparison

Rule Based (C^4)

Model Based (MPC)

Controller	$E_{TABS,prim}$ (kWh/m^2)	$E_{AHU,prim}$ (kWh/m^2)	$E_{TOT,prim}$ (kWh/m^2)	DC (Kh)
C^4	0.12	0.01	0.13	0.81
MPC	0.00	0.01	0.01	1.59

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Conclusions: TABS important features

- Limited thermal power
- Slow reacting system
- High start-up thermal power
- (CCA requires) a high quality building
- Allow temperature drift in the building zone
- No individual zone control

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Conclusions: rule based control

- Control strategy determines size of production system
- No heating/cooling switching in 1 day
- Rule based control: $T_{TABS} = T_{comfort,min} + 1°C$
- No feedback on zone temperature
- Alternating zone operation to reduce production power

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Conclusions: MPC

- Good candidate for integrated control
- Controlling CCA + fast system (AHU)
- Sensitive to errors
  - Model
  - Predictions
  - Measurements
  - Cost function

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Thank you